Agricultures
et défis du monde
Collection Cirad-AFD

The agroecological transition of agricultural systems in the Global South

F.-X. Côte, E. Poirier-Magona,
S. Perret, P. Roudier,
B. Rapidel, M.-C. Thirion,
éditors

éditions Quæ

Chapter 2

Agroecology in Madagascar: from the plant to the landscape

Krishna Naudin, Patrice Autfray, Julie Dusserre, Éric Penot, Louis-Marie Raboin, Tahina Raharison, Jacqueline Rakotoarisoa, Alain Ramanantsoanirina, Meva Tahiry Randrianjafizanaka, Laingo Irintsoa Rasolofo, Harinjaka Raveloson, Mamy Razafimahatratra, Paulo Salgado, Mathilde Sester, Kirsten Vom Brocke, Éric Scopel

Introduction

Context and problem

The Vakinankaratra region, located at the centre of the island of Madagascar, straddles two biogeographic zones that present stark physical and human differences: the highlands and the Middle West area (Figure 2.1). Research and development teams located in Antsirabe have been working for over 30 years to extend support for a sustainable intensification of agricultural production in the region. Various agro-ecological solutions have been explored for this purpose in order to make the best possible use of the available natural resources and in an effort to maintain coherence between farms in all their diversity. More or less complex innovations, sometimes combining different options, were envisaged depending on the context.

The average altitude of the highlands of Vakinankaratra is 1400 m, and the mean annual rainfall there is 1300 mm. Human settlement in this area dates back more than 2000 years, resulting in a high population density (over 120 inhabitants/km^2). The farms here are characterized by small surface areas (0.5 ha on an average), labour-intensive farming systems, a very low level of use of inputs, and the cultivation, when possible, of an off-season crop in irrigated areas. Irrigated areas and rainfed farming areas on the *tanety*[1] (hillsides) are already occupied. Cultivation systems in the developed lowlands are based on irrigated rainy season rice, with rice yields of about 3 t/ha, followed in the off-season by market gardening (potato, tomato, carrot) and/or fodder in the case of dairy farmers. The main productions of the farming systems in the *tanety* include rainfed rice (in expansion), maize, sweet potato, beans,

1. *Tanety*: rainfed farming (solely dependent on rainfall for its water supply) practised on the slopes and hilltops.

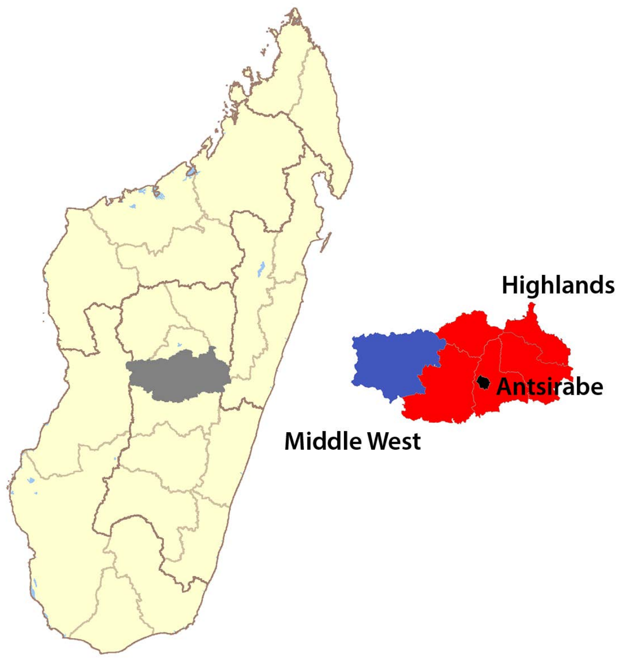


Figure 2.1. Location of the highlands and Middle West area in the Vakinankaratra region, Madagascar (from a Wikipedia map – Privatemajory CC BY-SA).

Bambara groundnut (*Vigna subterranea*), cassava, potato and peanut. In the context of a growing population, rainfed rice has become an extremely important component of the overall rice production that forms the staple of the Malagasy diet. The increase in the production of rainfed rice is the result of the adoption of a Nepali variety that is particularly suited to local conditions, as also of varieties originating from local research institutions (Penot *et al.*, 2016; Raboin *et al.*, 2014). Crop-livestock integration is widespread and manure remains the primary source of fertilization for crops. Livestock husbandry also provides a local opportunity to leverage plant resources and increase revenues. The problem faced by farmers with limited arable land is their inability to increase land productivity because they have very limited access to conventional intensification methods (fertilizer, mechanization, pesticides), and this in a fragile environment and with fairly steep slopes.

Madagascar's Middle West is at a lower altitude, of around 800 m. While the chemical fertility of soils is low (desaturated ferralitic soils) their structure is good. The climate is tropical with a rainfall of 1000 to 1500 mm/year spread over four to five months. These are areas that have only recently been settled (in the 1960s), and thus have a lower population density (30 to 40 inhabitants/km^2) and surface areas of the farms are bigger than in the highlands (Penot *et al.*, 2016). It is an agricultural frontier that is still undergoing a process of stabilization. The main crops are rainfed rice, maize and cassava on the *tanety*, and irrigated rice in the lowlands. Livestock farming is widespread because of the extensive natural pastures that exist relatively close to the major markets of the highlands. In this region too, the lowlands were cultivated first, even though their surface areas are smaller, and it is only now that the farmers are forced to cultivate the *tanety* with increasing regularity. However, as far as rainfed farming is concerned, the Middle West is characterized by the presence of a parasitic plant that is harmful to cereals: *Striga asiatica*. The rice varieties and cultivation systems that are being developed are thus intended, in addition to adapting to low fertility, to reduce the incidence of *S. asiatica*.

Actors and their roles

Malagasy development entities and CIRAD have been working together for close to 35 years to meet the challenges described above. Tafa, an NGO created in 1995, was thus assigned the objective of proposing an alternative to the soil tillage-based intensification model that was being promoted in Madagascar at that time. Based on initial experiments conducted in 1991 at the Andranomanelatra site (Antsirabe region) and with the support of L. Séguy of CIRAD, this NGO designed new farming systems based on conservation agriculture, and encouraged their dissemination by way of a number of demonstration plots spread over the country's main agroecological regions. The work of promoting conservation agriculture was extended across the country through the creation in 2002 of the Direct Seeding Group of Madagascar (GSDM), in association with other national and international partners (Compagnie Bas-Rhône Languedoc [BRL], Agrisud, Research and Technology Exchange Group [GRET]). Other technological solutions were also gradually incorporated into their extension work (agroforestry, vermicomposting). AFD supported these activities through various national projects and international programmes. In particular, from 2006 to 2012, it supported the development programme 'Irrigation and Watershed Management Project', whose aim was to increase the income of farmers in a sustainable manner, while conserving the environment through, *inter alia*, the promotion of agroecology. In parallel with these development-oriented actions, FOFIFA (National Center for Applied Research on Rural Development, Madagascar), the University of Antananarivo and CIRAD created a group towards the end of 2001 called 'Sustainable Farming and Rice Cropping Systems' to ensure agronomic and economic support for increasing the area under rainfed rice cultivation. This group's efforts were focused on two major innovations: on the one hand, the creation and dissemination of high-altitude rainfed rice varieties developed by the varietal-breeding programme launched by FOFIFA and CIRAD in the mid-1980s; and on the other, the creation and assessment of cropping systems based on conservation agriculture, disseminated by the NGO Tafa and CIRAD since the early 1990s. This Franco-Malagasy research group has progressed through different types of scientific collaboration, gradually broadening its research themes and its sphere of partnerships. Consequently, in 2013, the current mechanism for research in partnership 'Highland Production Systems and Sustainability' also brought in the French Institute of Research for Development (IRD), Fifamanor and AfricaRiceCenter.

Conceptual framework

Wezel *et al.* (2014) propose a classification of agroecological innovations according to the mechanisms they use and the extent of change required: increase in efficiency, substitution of external inputs, and redesign of systems. In the highlands and Middle West areas, the farmers' use of inputs is low. Consquently, the solutions proposed are based not so much on mechanisms of substitution as on increased efficiency and the redesign of systems.

We will first present two examples of an increase in efficiency at the scale of the plant, by showing how varietal breeding was focused on varieties that are naturally resistant to a fungal disease (blast), by better utilizing soil nitrogen and producing additional plant biomass, and thus becoming more competitive against weeds. We will also present an example of an increase in efficiency, at the intermediate scale of the livestock system, through the process of making manure, thus boosting nutrient recycling and increasing crop yields. We will see how an increase in efficiency can impact the farm. We will then present examples of how soil and crop management could be redesigned at the scale of cropping systems, based on new rainfed rice varieties and on conservation agriculture. The latter is an example of a more profound agroecological transformation from a systemic point of view and from the point of view of the mechanisms mobilized.

Two innovations based on an increase in efficiency

Varietal breeding adapted to low soil fertility and diseases

Plants that are better adapted to low fertility and diseases

The FOFIFA-CIRAD genetic improvement programme for high-altitude rainfed rice was launched in 1984 (Raboin *et al.*, 2013). Its aim is to breed varieties adapted to the biophysical environment of the highlands (cold, disease pressures, low fertility) as well the socio-economic context of farms (limited capacity to buy chemical inputs). In these cold altitudes, a strong correlation was observed between the vegetative development of rainfed rice varieties, measured in terms of leaf area index, and grain yield (Figure 2.2). A correlation was also shown between grain yield and length of the cycle. Under conditions of no mineral fertilization, the long-cycle and fast-developing varieties accumulate more nitrogen from mineralization over time, resulting in a higher yield. However, the cycle cannot be stretched indefinitely as the risk of cold and sterility increases as the rainy season draws to a close. Moreover, farmers are happy with relatively early varieties to shorten the duration of the lean season. Finally, this rapid development allows rice to offer more competition to weeds (Figure 2.2, Raboin *et al.*, 2014). It is also necessary to select varieties that are resistant to blast, a very common fungal disease which, in the worst case, can result in the loss of the entire crop (Pennisi, 2010), and against which chemical control is too expensive. To this end, epidemiological conditions favourable to the disease must be retained in the breeding process by applying nitrogen fertilizers and using sensitive varieties as border crops to attract pest. The border crops promote a local infestation of blast in order to subject the newly bred varieties to a strong disease pressure. It was therefore necessary to find a compromise to reconcile a selection for 'low input' conditions and for a trait that is resistant to blast. The use of inputs was greatly reduced during genealogical selection. In addition, the breeding selection stages, in which yield is assessed (varietal trials), were split between two levels of fertilization: with or without the use of chemical inputs.

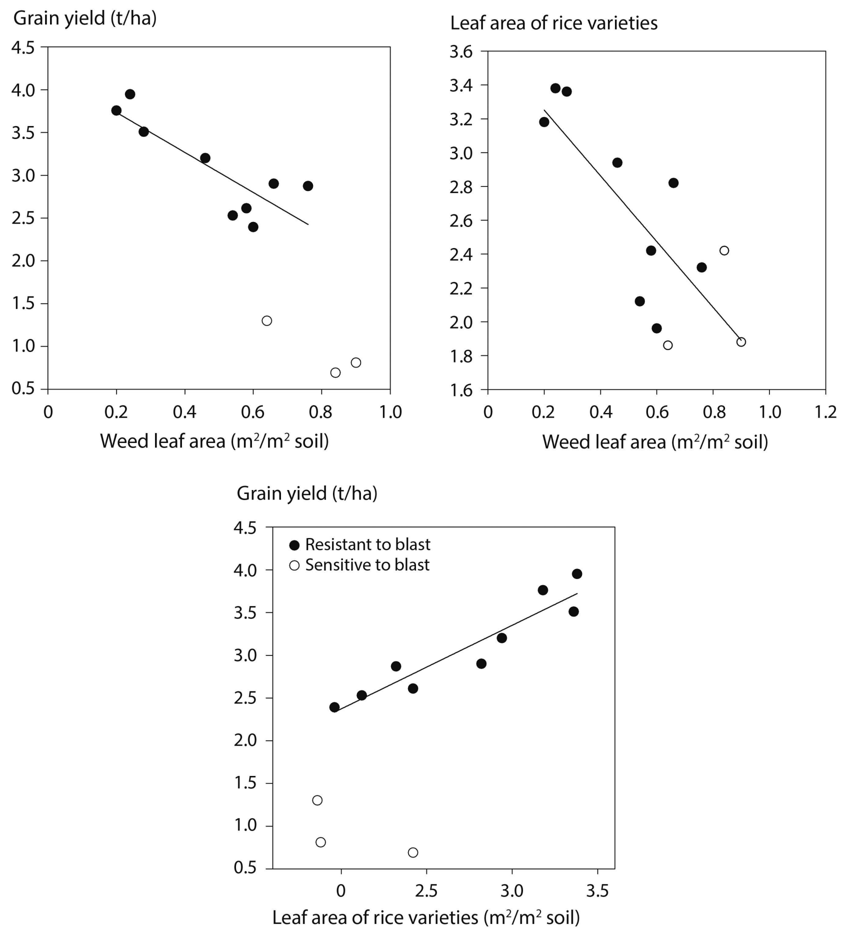


Figure 2.2. Relationship between grain yield, leaf area of weeds and leaf area of the varieties observed at an altitude of 1650 m, for a sample group of 12 rainfed rice varieties (Raboin *et al.*, 2014).

Consequences on production systems and the landscape

More than 20 varieties of upland rainfed rice have been proposed by the research community to farmers since 1994. The expansion of the cultivation area of rainfed rice to altitudes greater than 1800 m was rapid, due largely to the introduction of suitable varieties that allowed cultivation at these higher altitudes. Thus, between 2005 and 2011, the percentage of farms located above 1250 m cultivating rainfed rice in Vakinankaratra jumped from 32% to 71% (Raboin *et al.*, 2014). Improved efficiency at the scale of the rice plant resulted in changes in cropping systems on farms, and a change visible at the landscape scale. A participatory assessment of the impact of upland rainfed rice was conducted in 2015. It highlighted these rice varieties' importance in farm strategies that prioritized food security. These varieties had a significant impact on improving self-sufficiency in rice cultivation (the lean season was reduced by 3.7 months in the 112 farms surveyed) and on the well-being of farming households in the Vakinankaratra region (Breumier *et al.*, 2018).

Reduction in nutrient losses at the farm scale

Technical changes in the livestock farming system

The use of livestock manure to maintain the fertility of cultivated soils is the primary method of fertilization used by farmers. However, the fertilization value of manure varies significantly between farms. Measurements on 60 farms showed that the nitrogen content of manure could vary from 0.6% to 2.6% (Salgado *et al.*, 2014). Malagasy researchers associated with CIRAD have studied the main sources of variability in its quality, and measured the impact of improved manure on crop yields.

Based on these observations, three types of technical recommendations for improving the quality of manure have emerged: the addition of rice straw to excrement, the paving of barn floors to limit infiltration losses, and adequate management and protection of the stored manure until it is applied to the field.

Management and storage methods strongly influence the manure's nitrogen content (Andriarimalala *et al.*, 2013). It is important that vegetable matter rich in carbon (straw, dead leaves, small branches) are placed at the bottom of the pile, and matter rich in nitrogen (fresh leaves, peels and, in particular, animal residues such as excreta, slurry, etc.) is placed on top. This technique promotes degradation by microorganisms which use nitrogen from the upper layers to rapidly decompose the carbon-rich portion in the lower layers (Rabenandro *et al.*, 2009). In addition, it is preferable to place the manure in pits with a roof cover (Figure 2.3) as this helps limit nutrient losses by leaching during rains or by volatilization due to high temperatures (Salgado *et al.*, 2012).

The impact on cropping systems

The quantities of organic manure that farmers have is often insufficient for their cultivable area and requirements. Consequently, they choose to fertilize first the crops that bring in the maximum revenue per hectare. This, most often, turns out to be off-season market gardening in the rice fields. Rainfed plots (*tanety*), the least fertile, are therefore the least fertilized. Reducing nutrient losses by improving the manure production process is thus a preferred path to enhance the limited resources of the farm. Thus, a study in 2014 and 2015 compared the use of improved manure with that of conventional manure on the yield of rainfed rice in two adjacent plots on farms of 19 farmers (Figure 2.4). In both years, the yield of rainfed rice was higher by about 1 t/ha with the improved manure. In this case, improved manure was approximately twice as rich in nutrients, with 26 g N/kg DM (nitrogen per kilogram of dry matter) and 5.5 g P/kg DM (phosphorus per kilogram of dry matter) as against 13 g N/kg DM and 3.6 g P/kg DM respectively for conventional manure.

The impact at the farm scale is still little studied

Research on the socio-economic impact of manure improvement has shown that the adoption of these practices does not translate into a significant increase in the cost of manure production, despite the investments and the additional labour necessary.

The purpose of increasing the efficiency of manure utilization is to increase crop production, while deriving as much value as possible from farm resources by reducing nutrient losses at the scale of the production system. From the farmers' point of view,

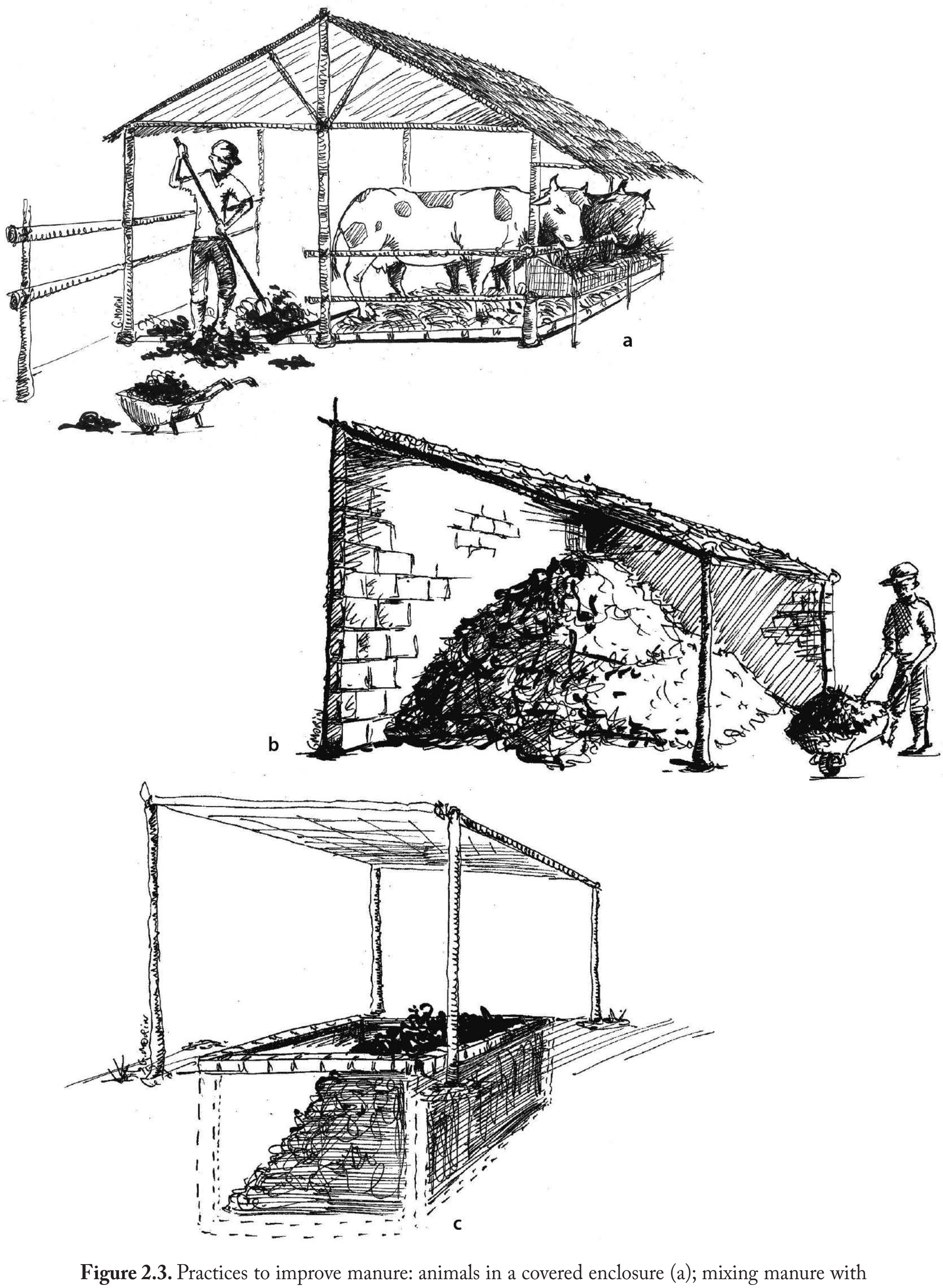


Figure 2.3. Practices to improve manure: animals in a covered enclosure (a); mixing manure with other sources of organic matter from the farm (b); manure covered with a roof and placed in a pit (c). Salgado *et al.* (2012), drawings by G. Morin.

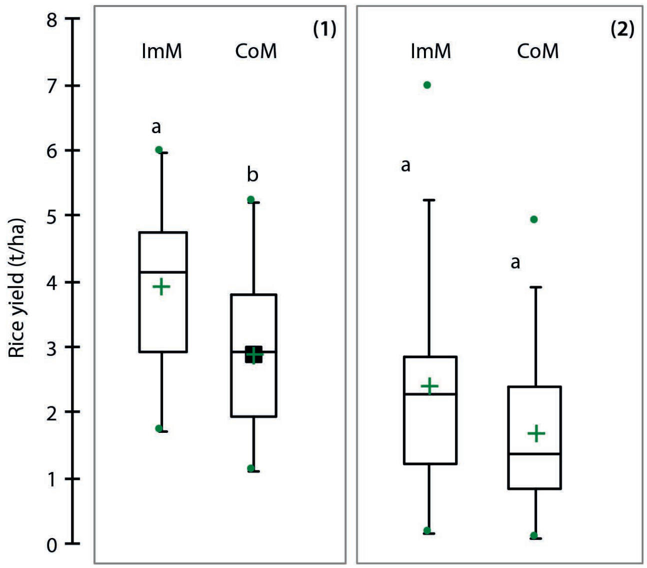


Figure 2.4. Grain yield for rainfed rice in 2014 (1) and 2015 (2) based on the type of manure used (Rasolofo, 2017).

ImM: improved manure; CoM: conventional manure. The letters correspond to the difference of treatments in a year, Tukey HSD test plots, $\alpha = 0.05$. N = 19 plots per year, variety 'Chhomrong Dhan', same source of improved manure for all plots.

this technical solution does not preclude the use of mineral fertilizers. Most of them are aware of the synergistic effects between mineral fertilizers and organic manures. They thus favour ecological intensification solutions, as defined by Griffon (2013), by combining agroecological solutions and mineral inputs. However, like other agroecological practices, the trade-off is that this solution requires more labour and technical skills, with consequences on the organization of the time invested, either in developing manure production areas, or in learning. The motivations that convince producers to make this investment need to be studied further.

Innovations based on the redesign of systems

We present two examples of the redesign of cropping systems, first through intra-specific diversification (mixture of varieties) to fight a rice disease at different scales, and then through supraspecific diversification (different plant species) associated with changes in tillage management (conservation agriculture) to improve soil fertility and pest control (weeds).

Mixtures of varieties to control blast

At the plot scale

Blast, which has long been at the centre of the breeding programme for rainfed rice, is caused by the pathogenic fungus *Magnaporthe oryzae* (Ou, 1985). The symptoms first appear on the leaves, which reduces the leaf area available for photosynthesis, and then spread to the peduncle where necrosis prevents grain filling (Figure 2.5a). The first rainfed rice varieties adapted for high altitudes were quickly attacked, while the later varieties, now bred specifically to withstand blast pressure, are much more tolerant. The pathogen, however, adapts very quickly, and the risks of circumvention of plant resistance remain high.

Several approaches have been explored to limit blast pressure on rainfed rice and to delay the risk of circumvention of the resistance of new varieties. The first is the varieties mixture, a mechanism that has proven itself in many plant-pathogen systems. Researchers tested the impact of blast on a very sensitive variety grown as a pure crop or mixed with a resistant variety (Raboin *et al.*, 2012; Raveloson *et al.*, 2016; Figure 2.5b). Mixing led to a significant reduction in the severity of the disease on susceptible varieties. The deployment of this type of mixture could promote the continued cultivation of certain sensitive varieties that are particularly popular with consumers, even in the case of disease pressure. The effects of mixing varieties on the dynamics of epidemics result from several mechanisms: a dilution effect, a physical barrier to the spread of spores among sensitive plants, and induced resistance that comes from interactions between plants.

Figure 2.5a. Typical symptom of panicle blast (sterile panicle). © Mathilde Sester/CIRAD.

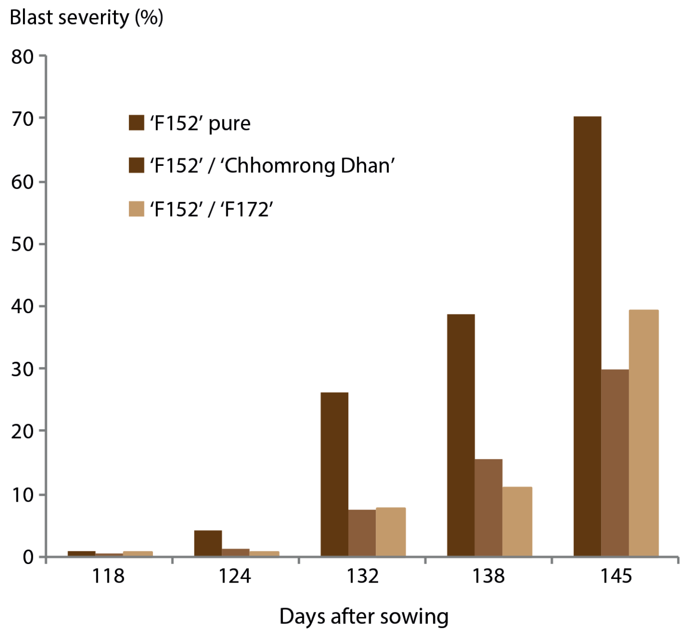


Figure 2.5b. Change in the percentage of grains attacked by blast for the F152 (susceptible) variety cultivated as a pure crop or as a mixed crop (one row of sensitive plants for four rows of resistant plants) with the varieties 'Chhomrong Dhan' (tolerant) or F172 (resistant), in 2012.

Varietal mixtures, much like the use of selected varieties, allow farmers to continue growing rainfed rice without having to use fungicides to control blast.

At the landscape scale

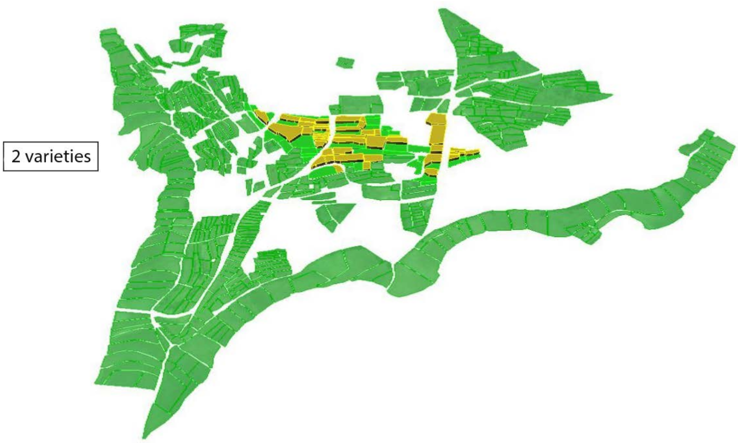
Blast pressure on rainfed crops has greatly decreased in rural conditions since the massive dissemination of a tolerant variety ('Chhomrong Dhan'). However, this situation can quickly become threatened if the pathogen adapts to this variety. A model was programmed in the Ocelet language (Degenne and Lo Seen, 2016) to determine the impact of the agronomic management of each plot and the varietal diversity at the landscape scale on the risk of propagation of the disease (Raveloson *et al.*, 2016; Sester *et al.*, 2016). This model makes it possible to compare a cultivated landscape with one or two varieties of rainfed rice (example of the results after five years of simulation is shown in Figure 2.6). The number of plots affected and the severity of the disease increase much more rapidly if only one variety is grown uniformly in the landscape.

Such studies show that agroecological pest management methods often involve solutions at scales beyond that of the mere plant we are trying to protect.

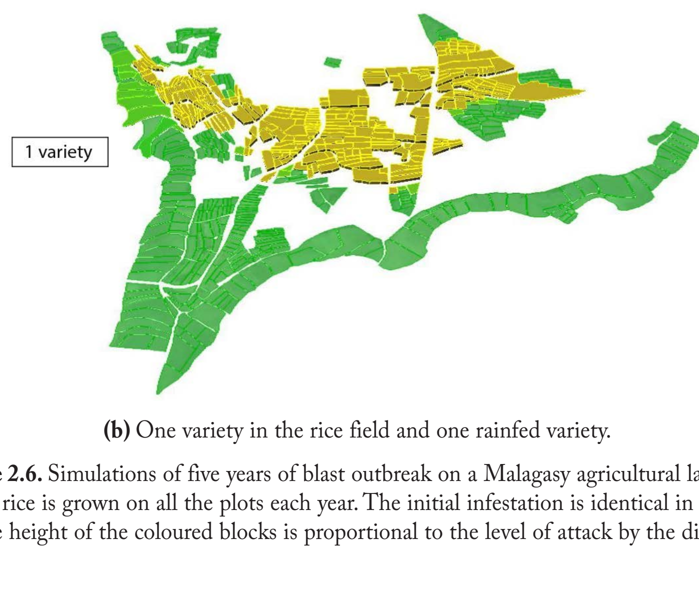
Soil management and interspecific diversification: conservation agriculture

Following the expansion of rainfed cultivation on hills in the highlands region, alternative farming systems based on conservation agriculture (based on three principles:

no-tillage, organic mulch, crop rotation) were recommended to reduce erosion and improve the sustainability of these cropping systems (Husson *et al.*, 2013). Conservation agriculture is a systemic alternative, in line with agroecology, in that it aims to increase production by mobilizing several agroecological functions of cover crops and the biomass produced (Ranaivoson *et al.*, 2017), as also to reduce the negative impacts of cultivation on soils by stopping their disturbance through mechanical tillage. Conservation agriculture and mulch-based direct-seeding system are terms that encompass a large range of farming systems with varied performances. In the highlands, the results in terms of erosion reduction are quite clear. For example, an experiment carried out from 2004 to 2009 showed that the average carbon, nitrogen and phosphorus erosion losses in tillage systems were respectively 336, 26 and 7 kg/ha/year, as compared to 6.35, 0.53 and 0.14 kg/ha/year in a conservation agriculture system (Razafindramanana *et al.*, 2017).



(a) One variety in the rice field and two rainfed varieties.



(b) One variety in the rice field and one rainfed variety.

Figure 2.6. Simulations of five years of blast outbreak on a Malagasy agricultural landscape in which rice is grown on all the plots each year. The initial infestation is identical in both cases. The height of the coloured blocks is proportional to the level of attack by the disease.

Mixed results for rainfed rice yields

An experiment was set up in 2004 in Andranomanelatra, on the highlands (1640 m), to assess the performance in grain yield and biomass production of conservation agriculture systems practised in a biennial rotation with rainfed rice. These systems have evolved over time, as shown in Figure 2.7.a, towards a production with greater biomass due to a rotation with rice (the proposed maize-based systems associated with a legume was retained here). Rice yields, lower in mulch-based systems than in systems that includes tillage for the first few years, became comparable from the sixth year onwards (Figure 2.7.b).

A more detailed study of some systems (2005 to 2007) showed that establishing a crop was more difficult in conservation agriculture, with slower root growth, and led to a reduced development of rice and of nitrogen uptake (Dusserre *et al.*, 2012). However, under the same conditions, these systems have demonstrated their ability to provide more nitrogen, which, however, is not utilized by the crop (Rakotoarisoa *et al.*, 2010).

Contradictory effects on blast

The dynamics of blast epidemics were studied in conservation agriculture systems in the highlands. Monitoring in conventional systems has shown that the epidemic develops more rapidly following the first signs of leaf attack. At the time of the harvest, the percentage of empty grains due to the disease is generally lower in conservation agriculture due to different nitrogen assimilation (Dusserre *et al.*, 2017; Sester *et al.*, 2014). However, the lower stand density of rice in conservation agriculture, compared to that in a tillage system, could also be the cause of this difference in outbreaks. In addition, the practice of leaving rice straw on the fields in conservation agriculture systems runs counter to the preventive measures to be taken in case of the occurrence of the disease. Indeed, studies by CIRAD and FOFIFA have shown that straw can serve as a reservoir of blast spores for up to 18 months after the harvest (Raveloson *et al.*, 2018). This is an example of a trade-off that farmers have to accept when practising agroecology. The research community has to better quantify these contradictory effects in order to inform decision-making by development agencies, policymakers, administrative authorities and farmers.

A practice still little adopted on the highlands

The lack of quick and clear results on crop yields, the competition for residues, and the increased technical skills required for systems in conservation agriculture result in few farmers practising it in the highlands (Hartog *et al.*, 2011; Randrianarison *et al.*, 2007). While the overall working time is reduced in conservation agriculture due to the elimination of manual tillage, it is not sufficient to offset other technical problems, particularly those related to the effectiveness of various associated cover crops. In addition, most farmers do not have the necessary financial capacity to set up these systems, which are initially very intensive, as advocated by their proponents (Cavellier de Cuverville *et al.*, 2010). The time required for a return on investment is often too long.

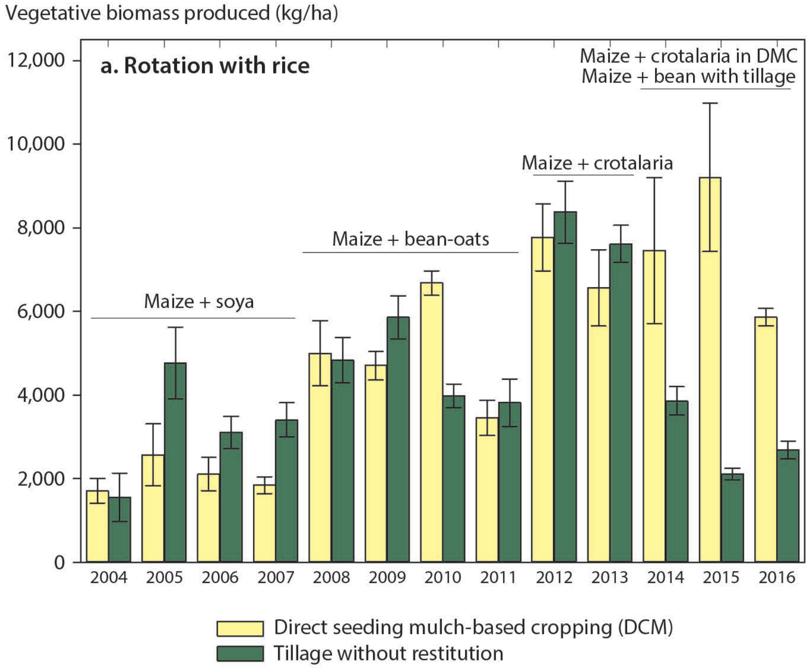


Figure 2.7a. Change in biomass production of crops in rotation with rainfed rice as recorded during the Andranomanelatra experiment from 2004 to 2016 (unpublished data).

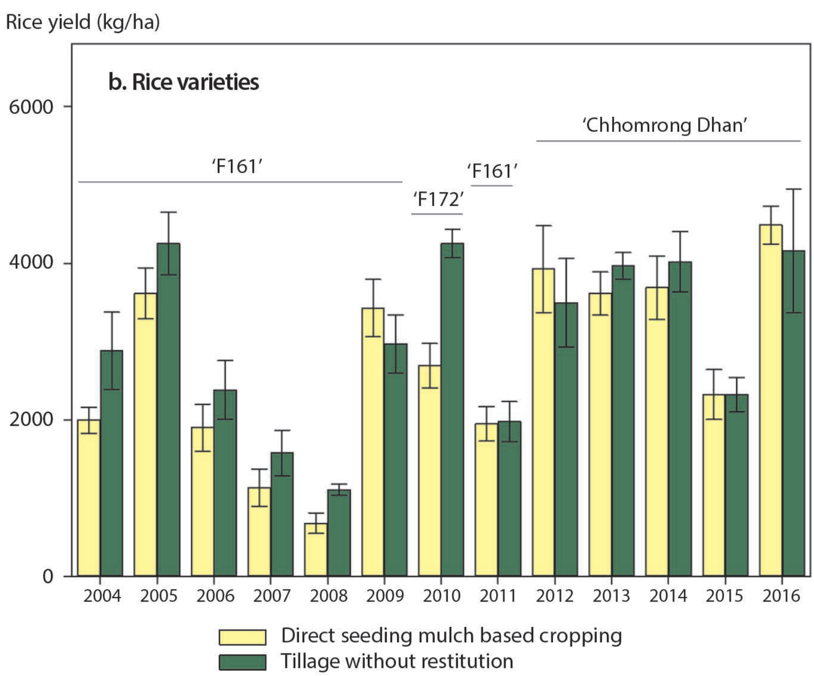


Figure 2.7b. Change in rainfed rice production for the Andranomanelatra experiment from 2004 to 2016 (unpublished data).

A cohort analysis (Randrianarison *et al.*, 2007) of the dissemination of techniques in conservation agriculture around the Tafa station revealed the main reasons for abandonment:

– the improvement of the soil water balance is not critical in the highland environment;
– production costs related to the adoption of these systems are too high during the installation phase;
– after the fifth year of adoption, the reasons for abandonment mentioned by farmers are generally economic ones (an insignificant increase in yields and in gross margin per hectare for producers and a low return on investment) or social ones (difficulty in managing cattle roaming and grazing and great difficulty in organizing producers into associations or cooperatives).

A broader study in the intervention areas of the project 'Irrigation and Watershed Management in the South-East Highlands' (BVPI/SE-HP) showed the same constraints for the same effects (Hartog *et al.*, 2011), with a proven and long-standing reliance on the effectiveness of tillage that is not matched by the expected effects of conservation agriculture with no-tillage conditions. Thus, the majority of farmers assume soils will be compacted after five years of conservation agriculture. The strategies of local farmers are clearly driven by short-term concerns of food self-sufficiency and a rapid conversion of any possible production surpluses into economic benefits, whereas conservation agriculture requires a judicious management of resources and a projection of production over the long term. For example, there is no space for improved non-productive fallows. The cold temperatures in the dry season, the lack of a locally adapted service plant and the absences of increase in yields (when mineral fertilizer is not used) have clearly limited the interest in conservation agriculture. The few farmers who have adopted these systems are the ones who are better off, for whom technical and social constraints are less restricting (Hartog *et al.*, 2011). These sets of constraints are similar to those found elsewhere in Africa for this type of system (Corbeels *et al.*, 2014).

Better agronomic results in the Middle West

More recently, studies were conducted in the Middle West area for a more detailed understanding of the dynamics of soil nitrogen in mulch-based cropping systems, and the impact of different types of crop residues on rice. First, a short-term experiment on the rainfed rice/*Stylosanthes guianensis* rotation, showed that even though *S. guianensis* is capable of fixing large amounts of atmospheric nitrogen and generating significant biomass, the end release of nitrogen to rice was low in the initial years of cultivation (only 5% to 8% of the nitrogen originating from the *S. guianensis* mulch was used by the rice, according to Zemek *et al.* [2018]). On the other hand, in an older set-up, in two-year-old rural farming systems based on rainfed rice and 4- to 10-year-old *S. guianensis* (Figure 2.8), the yield of rice was improved in mulch-based systems after a *S. guianensis* crop. However, this conservation agriculture system requires additional work, especially during sowing, due to the presence of a thick groundcover (8 t/ha DM on average).

While *S. guianensis* was introduced for its ability to quickly colonize poor soils, it also possesses the capability of controlling the outbreak of striga, a characteristic plant parasite of this region, on rice and maize crops. In 2015, harvests in seven partner

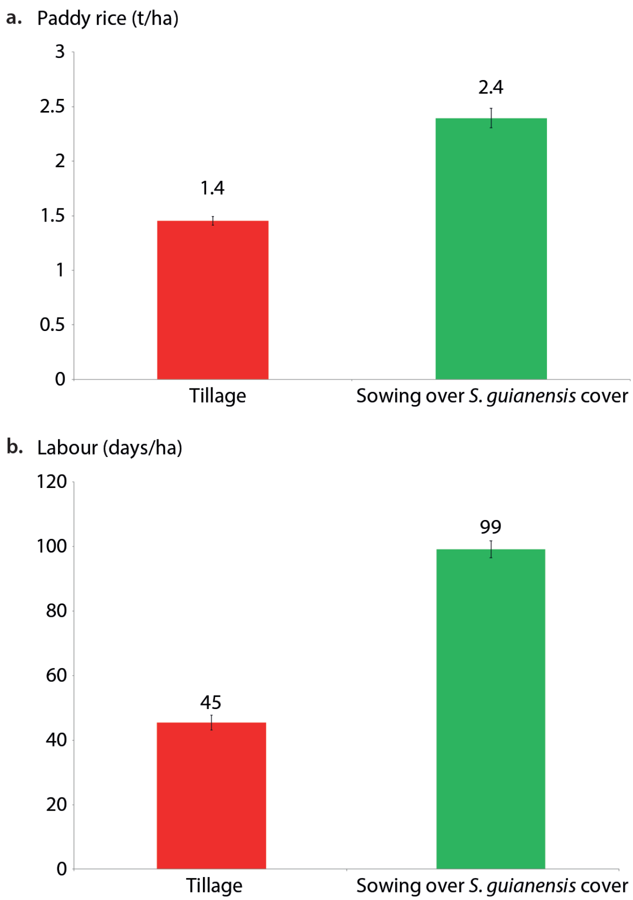


Figure 2.8.a. Comparison of farm yields for rice cultivation based on tillage (24 plots) with those based on conservation agriculture with a cover of *S. guianensis* (19 plots), 2016 and 2017 harvests (Autfray *et al.*, 2018). b. Comparison of working time in a farm for rice cultivation based on tillage (24 plots) with those based on conservation agriculture with a cover of *S. guianensis* (19 plots), 2016 and 2017 harvests (Autfray *et al.*, 2018).

farms have shown that the yield of the B22 variety, highly valued but very sensitive to striga, was similar (1.8 t/ha on average) when grown in rotation with *S. guianensis* to that of the Nerica4 variety, which was newly introduced and is resistant to striga. On an average, in an experiment conducted over four consecutive years with tillage, the rate of infestation of B22, as compared to Nerica4, was about ten times higher, resulting in lower yields. However, the infestation rate, compared in the same period, dropped from 2.1 to 0.4 plants/m^2 in a system that included *S. guianensis*, and from 3.4 to 0.3 plants/m^2 for maize (Randrianjafizanaka *et al.*, 2018).

The beginning of adoption in the Middle West

The history of the dissemination of mulch-covered cropping systems around Ivory in the Middle West area since 1998 shows that farmers find it hard to adopt conservation agriculture in a sustained manner without the continuous support of technical experts.

Two studies in the Ankazomoriotra and Vinany communes, in a mid-altitude zone (900-1100 m) (Quiennec *et al.*, 2013), helped characterize farms, identify a typology, and measure the adoption of conservation agriculture systems (five years after their introduction), based on farm type and size. Observations since 2005 in the area of operation of the development actor FAFIALA have shown that the very smallest farmers who adopt conservation agriculture systems obtain a net agricultural income that is lower than from traditional systems. On the other hand, farmers with a medium to large agricultural areas (bigger than 5 ha) manage to increase their cultivated areas by adopting conservation agriculture systems (due to the reduction of fallow time) and thus increase their net agricultural income. In all, out of 1318 ha monitored by the AFD-funded project 'Irrigation and Watershed Management in the South-East Highlands' (BVPI/SE-HP), conservation agriculture was practised on 450 ha of them in 2011 (Penot *et al.*, 2011). Surveys also revealed that conservation agriculture systems proved effective against the adverse effects of striga, allowing for rotations focused primarily on cereals. On the other hand, the working time saw a significant increase in systems based on *Stylosanthes* spp. Studies for modelling revenue (Charentenay and Penot, 2012) showed a small positive impact on incomes (an extra 10 to 19% over five years), as the results of adopting conservation agriculture are only felt in the medium term, following the stabilization of production, without any significant increase in yields. Such a shift in paradigm and farmer strategy from the short to the medium term cannot be achieved in less than six years. While conservation agriculture is still challenging and unsuitable for the highlands in a very specific land and social context, it does constitute a potential alternative for sustainable agricultural development in the Middle West area due to the diversity of the systems proposed and the possibility of maintaining cereal cultivation despite the presence of striga.

What changes does agroecology entail in research work?

This work on agroecological solutions, which has spanned many years, has led researchers to work in a different way, especially as concerns interactions with farmers.

Participatory breeding

Participatory breeding consists of a closer involvement of small farmers in the creation, selection and dissemination of plants, in conjunction with a continuous dialogue or exchange between farmers and researchers. To fine-tune rainfed rice varieties to the farmers' needs, part of the breeding work must be done on their plots with their participation (Photo 2.1). This is especially true for farms with little intensification and therefore particularly subject to the heterogeneity of environmental conditions. This is why a participatory varietal assessment network is created every year in partnership with different actors, who have changed over time (farmer organizations, NGOs, projects, research or training institutions). The rainfed rice breeding programme is also evolving towards a greater involvement of farmers by increasingly involving them earlier in the breeding process, including in the experimental station phases. It is through this approach that four new lines have been identified as more efficient and more appreciated than the control plants corresponding to the two targeted ecology types.

Photo 2.1. Participatory assessment of new rainfed rice lines by women farmer groups in the Middle West area in 2015. The participatory approach allows, for example, the taking into account of the preferences of choices according to gender in the breeding process. © Kirsten Vom Brocke/CIRAD.

Innovation platform

In the Middle West area of Vakinankaratra, the Stradiv[2] research project is testing new approaches to a participatory design of cropping systems, based on a permanent link between activities carried out on reference farms and those of the experimental mechanism in nearby Ivory. This site integrates the breeding of rainfed rice, various thematic experiments and a technical reference base for imparting training to the Direct Seeding Group of Madagascar (GSDM). Thematic diagnoses of constraints and performance monitoring of different plots are continuously carried out on the reference farms. The selection of innovative systems is first undertaken with a specific experimental mechanism allowing a joint assessment by researchers and farmers of a large number of strip-plot modalities. Subsequently, the cropping systems are implemented by farmers in reference farms for an economic assessment and integration at the farm scale. This approach helps combine local and scientific knowledge on practices and technical models, in order to quickly select, over time and space, the best arrangements and methods of crop management (Autfray *et al.*, 2018).

Assessment at the farm scale and management of trade-offs

As we have shown in the preceding examples, farmers may be forced to make trade-offs between different objectives in their agroecological practices. For example, allowing the rice straw to remain on the field can help control soil erosion but, at the same time,

2. *System approach for the TRAnsition to bio-DIVersified agroecosystems, from process analysis to multi-scale co-conception with actors*, project funded by the Agropolis Foundation.

will reduce the amount of high-quality manure produced and could lead to continued fungal disease pressure. It is therefore important to assess the technical options from every angle. For example, Rasolofo (2017) studied the performance of three cropping systems in terms of productivity, potential to maintain soil carbon content, and the possibility of recycling aboveground biomass as a forage resource. Figure 2.9 shows the impact of the off-plot export of 0 to 100% of residues on potential milk production from these residues and the amount of nitrogen returning to the soil from the residues left behind. We can observe that milk production can be increased substantially without significantly compromising the return of soil nitrogen by plant residues. Indeed, a part of the nitrogen returned is from roots which, in any case, remain in the soil even if the entire aboveground biomass is used. The recommendations must take into account the constraints and objectives of the farmers in terms of production and maintenance of fertility, which differ depending on the types of farms.

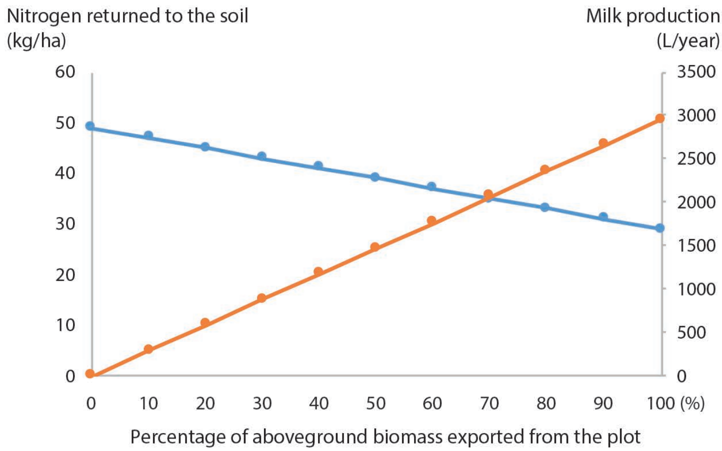


Figure 2.9. Simulation of the amount of nitrogen from crop residues returned to the soil (left axis) and the amount of milk (right axis) that can be produced, by using 0 to 100% (x) of the aboveground plant biomass from a rainfed rice/maize + bean rotation system (Rasolofo, 2017).

Conclusion

More than 30 years of research and development on agroecology in Vakinankaratra has resulted in varying degrees of adoption of innovations developed by researchers jointly with farmers. In particular, there exist differences within the region that can be explained, in part, by the performance of cropping systems, the pressure on residues, and the agronomic, economic and social problems confronting farmers.

The practice of conservation agriculture involves quite profound changes, not only in cropping systems, but also in production systems: land allocation, labour distribution. In addition, in a context in which farmers lack easy access to technical references, the adoption of these new complex systems represents a significant risk of technical failure. Thus, many farmers with difficult economic conditions are reluctant to make drastic changes to their production system because of the risks such changes pose for their food and economic security. In this context, it is the simplest and least risky innovations that are adopted first by farmers. Consequently, new rainfed rice varieties, whether imported or locally selected, are adopted very rapid. These varieties have the advantage of being eminently suitable for already existing cropping systems that use little or no mineral fertilizer or herbicide. They offer an opportunity to increase production of rice and contribute to the region's food security without having to resort to complicated techniques.

As of now, there has been no major redesign of production systems in Vakinankaratra driven by research on agroecology. Nevertheless, as we have seen, by creating new tools that structure interactions with local actors in a participatory approach, more complex components of 'agroecological systems' are gradually being adopted: varieties, improvement in the efficiency of nutrient recycling, cultivation of service plants to control striga and/or produce fodder, etc. Farmers in Vakinankaratra benefit from a range of technical options that they are beginning to implement. It can therefore be expected that the intensification of production systems will gradually become a reality, and that it will happen through the mobilization of a significant number of the ecologically intensive options now available to the farmer and not on the basis of conventional intensification solutions (chemical inputs, mechanization, etc.), which are, in any case, still inaccessible to many small producers in these regions. However, it will be necessary to continue working with local actors to intensively and efficiently support the innovation process around these alternatives.

References

Andriarimalala J.H., Rakotozandriny J.N., Andriamandrosoa A.L.H., Penot E., Naudin K., Dugué P., Tillard E., Decruyenaere V., Salgado P., 2013. Creating synergies between conservation agriculture and cattle production in crop-livestock farms: A study case in the Lake Alaotra Region of Madagascar. *Experimental Agriculture*, 49, 352-365, https://doi.org/10.1017/S0014479713000112.

Autfray P., Raharison T., Ripoche A., Audoin S., Salgado P., Rakotofiringa H., Moussa N., Randrianjafizanaka M.T., Rafenomanjato A., Rasambatra E., Rakotoarivelo M., 2018. Conception participative de systèmes de culture innovants dans le Moyen-Ouest du Vakinankaratra (MOV).

Breumier P., Ramarosandratana A., Ramanantsoanirina A., Vom Brocke K., Marquié C., Dabat M.H., Raboin L., 2018. Évaluation participative des impacts de la recherche sur le riz pluvial d'altitude à Madagascar de 1980 à 2015. *Cahiers agricultures*, 27, 15004, https://doi.org/10.1051/cagri/2017065.

Cavellier de Cuverville T., Wampfler B., Penot E., 2010. Analyse des pratiques de crédit dans la zone du projet BVPI-SEHP (Vakinankaratra et Moyen-Ouest), working document AFD/BVPI/SE-HP no. 27, CD-ROM AFD/2011, https://doi.org/10.13140/RG.2.2.21149.36325.

Corbeels M., de Graaff J., Ndah T.H., Penot E., Baudron F., Naudin K., Andrieu N., Chirat G., Schuler J., Nyagumbo I., Rusinamhodzi L., Traore K., Mzoba H.D., Adolwa I.S., 2014. Understanding the impact and adoption of conservation agriculture in Africa: A multi-scale analysis. *Agriculture, Ecosystems & Environment*, 187, 155-170, https://doi.org/10.1016/j.agee.2013.10.011.

de Charentenay J., Penot E., 2012. Évaluation socioéconomique de l'impact de l'adoption des techniques de semis sous couvert végétal sur le revenu des agriculteurs du moyen-ouest de Madagascar (région d'Ankazomiriotra), projet Rime-Pampa, working document AFD/BVPI/SE-HP no. 47, 2009, CD-ROM AFD/2012, https://doi.org/10.13140/RG.2.2.12760.75521.

Degenne P., Lo Seen D., 2016. Ocelet: Simulating processes of landscape changes using interaction graphs. *SoftwareX*, 5, 89-95, https://doi.org/10.1016/j.softx.2016.05.002.

Dusserre J., Chopart J.-L., Douzet J.-M., Rakotoarisoa J., Scopel E., 2012. Upland rice production under conservation agriculture cropping systems in cold conditions of tropical highlands. *Field Crops Research*, 138, 33-41, https://doi.org/10.1016/j.fcr.2012.09.011.

Dusserre J., Raveloson H., Michellon R., Gozé E., Auzoux S., Sester M., 2017. Conservation agriculture cropping systems reduce blast disease in upland rice by affecting plant nitrogen nutrition. *Field Crops Research*, 204, 208-221, https://doi.org/10.1016/j.fcr.2017.01.024.

Griffon M., 2013. *Qu'est-ce qu'une agriculture écologiquement intensive ?* Quæ, Versailles, 224 p.

Hartog M., Penot E., De Graff J., Raharison T., 2011. Implementation of conservation agriculture in the highlands of Vakinankaratra, Madagascar: Constraints and opportunities, document de travail, projet CA2AFRICA 2011, Antananarivo, https://doi.org/10.13140/RG.2.2.21988.22400.

Husson O. (ed.), Séguy L. (ed.), Charpentier H. (ed.), Rakotondramanana (ed.), Michellon P., Raharison T., Naudin K., Enjalric F., Moussa N., Razanamparany C., Rasolomanjaka J., Bouzinac S., Chabanne A., Boulakia S., Tivet F., Chabierski S., Razafintsalama H., Rakotoarinivo C., Andrianasolo H.M., Chabaud F.X., Rakotondralambo T., Rakotondralambo P., Ramaroson I., 2013. *Manuel pratique du semis direct sur couverture végétale permanente (SCV) : Application à Madagascar*, GSDM/CIRAD, Antananarivo, Madagascar, 716 p.

Ou S.H., 1985. *Rice Diseases*, 2nd edition, Commonwealth Mycological Institute, Kew, United Kingdom, 380 p.

Pennisi E., 2010. Armed and dangerous. *Science*, 327, 804-805, https://doi.org/10.1126/science.327.5967.804.

Penot E., Raboin L.-M., Tokarski Y., Rakotofiringa A., Bodoy A., Ahmim Richard A., Dabat M., Rahahison T., Rakoto Harivony A., Razafimandimby S., 2016. Rôle et place du riz pluvial dans les exploitations du Vakinankaratra (Hauts Plateaux et Moyen-Ouest). *In*: *Processus d'innovation et résilience des exploitations agricoles à Madagascar* (E. Penot, ed.), L'Harmattan, Paris, 410.

Penot E., Sorèse J., Raharison T., 2011. Analyse de la situation des superficies en SCV dans le Moyen-Ouest avec l'opérateur Fafiala (projet BVPI-SE/HP), synthèse pour le projet Pampa, working document AFD/BVPI/SE-HP no. 17, CD-ROM AFD, 2012, https://doi.org/10.13140/RG.2.2.26182.52802.

Quiennec, M., Penot, E., Razafimahatratra Hanitriniaina, M., 2013. Caractérisation et typologie des exploitations agricoles du Moyen-Ouest du Vakinankaratra, Madagascar, working document UMR/Innovation/SPAD, 2013, https://doi.org/10.13140/RG.2.2.19471.64167.

Rabenandro T., Dupin B., Hyac P., 2009. *Guide synthétique d'agronomie et d'agro-écologie dans le contexte de la rive-ouest du lac Alaotra*, AVSF, 47 p.

Raboin L.-M., Ramanantsoanirina A., Dusserre J., Razasolofonanahary F., Tharreau D., Lannou C., Sester M., 2012. Two-component cultivar mixtures reduce rice blast epidemics in an upland agrosystem. *Plant Pathology*, 61 (6), 1103-1111, https://doi.org/10.1111/j.1365-3059.2012.02602.x.

Raboin L.-M., Randriambololona T., Radanielina T., Ramanantsoanirina A., Ahmadi N., Dusserre J., 2014. Upland rice varieties for smallholder farming in the cold conditions in Madagascar's tropical highlands. *Field Crops Research*, 169, 11-20, https://doi.org/10.1016/j.fcr.2014.09.006.

Raboin L., Dzido J., Ahmadi N., 2013. Création variétale pour la riziculture pluviale d'altitude à Madagascar : Bilan de 25 années de sélection. *Cahiers agricultures*, 22, 450-458, https://doi.org/10.1684/agr.2013.0624.

Rakotoarisoa J., Oliver R., Dusserre J., Muller B., Douzet J.-M., Michellon R., Moussa N., Razafinjara L.A., Rajeriarison J., Scopel E., 2010. Bilan de l'azote minéral au cours du cycle du riz pluvial sous systèmes de couverture végétale en sol ferrallitique argileux à Madagascar. *Étude et gestion des sols*, 17, 169-186.

Ranaivoson L., Naudin K., Ripoche A., Affholder F., Rabeharisoa L., Corbeels M., 2017. Agroecological functions of crop residues under conservation agriculture. *Agronomy for Sustainable Development*, 37, 26, https://doi.org/10.1007/s13593-017-0432-z.

Randrianarison N., Penot E., Poncet C., 2007. Suivi et analyse des succès et des abandons des systèmes à base de semis direct sous couverture végétale (SCV) : Mise au point de la méthodologie, Cas du fokontany d'Antsapanimahazo – Madagascar, working document AFD/BVPI/SE-HP no. 33, CD-ROM AFD, 2008, https://doi.org/10.13140/RG.2.2.32893.41448.

Randrianjafizanaka M.T., Autfray P., Andrianaivo A.P., Ramonta I.R., Rodenburg J., 2018. Combined effects of cover crops, mulch, zero-tillage and resistant varieties on *Striga asiatica* (L.). *Agriculture, Ecosystems and Environment*, *under finalization*.

Rasolofo L.I., 2017. Impact des innovations agro sur les flux de carbone et cultures pluviales : Cas des Hautes Terres de Madagascar, doctoral thesis, University of Antananarivo, Antananarivo, Madagascar, 161 p.

Raveloson H., Rafenomanjato A., Ramanantsoanirina A., Sester M., Raboin L., 2016. Gestion de la diversité variétale du riz pluvial pour contrôler la pyriculariose. *In*: *Recherche interdisciplinaire pour le développement durable et la biodiversité des espaces ruraux malgaches : Application à différentes thématiques de territoire* (D. Hervé, R.-A. Tantely, R. Jacqueline, R. Bruno, eds), SCAC/Parrur, Éditions MYE, Antananarivo, Madagascar, 137-167.

Raveloson H., Ratsimiala Ramonta I., Tharreau D., Sester M., 2018. Long-term survival of blast pathogen in infected rice residues as major source of primary inoculum in high altitude upland ecology. *Plant Pathology*, 67 (3), 610-618, https://doi.org/10.1111/ppa.12790.

Razafindramanana N.C., Marie J., Albrecht A., 2017. Effet des systèmes de culture en semis direct pour contrôler les pertes en carbone, azote et phosphore totaux par érosion hydrique sur les Hautes Terres de Madagascar. *Afrique Science*, 13, 341-353.

Salgado P., Rarivoarimanana B., Andriarimalala J., Nabeneza S., Tillard E., Decruyenaere V., Lecomte P., 2012. Pratiques paysannes et qualité fertilisante du fumier dans la région du Vakinankaratra et d'Amoron'i Mania, fiche technique.

Salgado P., Tillard E., Rarivoarimanana B., Decruyenaere V., Lecomte P., 2014. Management practices to conserve the fertilizer N value of dairy manure in Vakinankaratra region, Madagascar. *In*: *Agroecology for Africa, International Conference*, Antananarivo, Madagascar.

Sester M., Raveloson H., Degenne P., 2016. Modelling the impacts of varietal diversity and cropping system on the propagation of rice blast at the landscape level: Model construction. *In*: Rice Blast Conference, Manila, Philippines.

Sester M., Raveloson H., Tharreau D., Dusserre J., 2014. Conservation agriculture cropping system to limit blast disease in upland rainfed rice. *Plant Pathology*, 63, 373-381, https://doi.org/10.1111/ppa.12099.

Wezel A., Casagrande M., Celette F., Vian J.-F., Ferrer A., Peigné J., 2014. Agroecological practices for sustainable agriculture: A review. *Agronomy for Sustainable Development*, 34, 1-20, https://doi.org/10.1007/s13593-013-0180-7.

Zemek O., Frossard E., Scopel E., Oberson A., 2018. The contribution of *Stylosanthes guianensis* to the nitrogen cycle in a low input legume-rice rotation under conservation agriculture. *Plant and Soil*, 45 (1-2), 553-576, https://doi.org/10.1007/s11104-018-3602-0.